

# Recycled Plastics for Highway Agencies

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A description is presented of ongoing research by the Florida Department of Transportation on feasibility studies to use recycled plastic wastes for fence line posts and guardrail posts as mandated by a 1988 state law. All test work focused on acquisition of data for selected essential properties and characteristics, including durability; resistance to insects, soil microorganisms, and environmental exposure; water absorption; and flexural and tensile strength. Initial studies entailed property measurements of high-density polyethylene sheeting (milk bottles) used in A-frame barricades. Low strain rate tests produced failure at a strain of approximately 1.0 for flawed material but did not fail for flaw-free material at a strain of 2.6. Large-diameter posts showed major variations in composition and properties. Exposure tests showed warpage on posts with small cross sections. Flexure to failure whole post tests indicated that some posts were stronger than concrete and were possible candidates for guardrail posts. Resistance tests for soil microorganisms showed no effect. Boiling water and boiling saline had no effect on dimensional changes on most post discs. All discs absorbed liquid after 8 to 10 hr of exposure. Insect exposure tests (fire ants and termites) indicate that posts containing cellulosic material may not be suitable in termite-infested areas due to high weight loss. A fence post specification framework is proposed. Other components currently under testing and evaluation are listed.

It has been estimated that the construction, rehabilitation, and maintenance of the nation's highways annually requires 350 million tons of construction materials (natural and manufactured). This includes 20 million tons of asphalt, 10 million tons of portland cement, and 320 million tons of natural aggregates, paving mixtures, coatings, and so forth (1). Many state agencies have developed or are developing and implementing procedures to include a variety of waste materials in construction and rehabilitation processes. This is in response to increasing environmental concerns about solid waste disposal, environmental hazards, and location of new disposal sites.

The generation of large amounts of solid waste has created much concern at local and state government levels in Florida. The situation is aggravated by Florida's sensitive environment, vulnerable ground water supplies, and continuing need to find additional landfill capacity (2).

In 1988, the Florida legislature passed a comprehensive solid waste management bill (Senate Bill 1192) (3), which directed the Florida Department of Transportation (FDOT) to expand, where feasible, its use of recovered waste materials in highway programs. The legislation directed FDOT to initiate research using available expertise in the Florida state university system and to build demonstration projects for de-

termining the feasibility of using various solid wastes in construction projects. If use of these materials was found feasible, the FDOT was to develop appropriate specifications requiring the use of such waste materials.

The Florida legislation addressed, in part, the following specific waste by-products and applications for use in road construction:

- Recycled oil products,
- Ground rubber tires in asphalt pavement,
- Glass and glass aggregates,
- Recycled steel for rebar and I-beams,
- Recycled mixed plastic materials for guardrail posts and fence posts,
- Fly ash (Class F) in portland cement concrete construction, and
- Fly ash in soil stabilization.

The intent of the legislation was to promote waste by-product use to reduce the environmental impact of disposing of these wastes in Florida landfills. Current waste disposal practices encompass the potential for air and water pollution, health hazards, lack of suitable disposal sites, collection and disposal costs, and the loss of resources that may be economically and beneficially recovered through recycling (4).

Florida currently generates 15.8 million tons of municipal solid waste (MSW) annually. Of this amount, 8.8 percent, or 1.4 million tons, represents plastic wastes available for recycling. In 1988, only 1 percent of all plastic wastes was recycled. Despite this low figure, the plastics industry has pointed out that there is no technical reason preventing the recycling of plastics in the MSW stream (5). This paper focuses on plastic recycling in Florida and the potential and current use of recycled plastics by FDOT.

As a result of the 1988 legislation, recycling plastics became a popular topic. However, the effective use of recycled plastics requires that the plastics' property changes occurring because of the recycling be documented. Commingled (mixture of waste plastics) postconsumer plastic scrap is currently melt-extruded into post and board shapes. FDOT is investigating the possible use of recycled commingled plastics for highway applications such as guardrail posts and fence posts. These applications require that the range of mechanical properties be known so that specifications can be established. It is suspected that the commingled plastic materials may be flawed and have inadequate properties for some of these applications. Ultimately, the goal is to acquire reliable data to develop specifications for procurement of the materials through construction contracts. An initial maintenance contract to supply 5,000 fence posts is in progress.

Table 1 gives typical plastics currently in use and their applications. The table includes the recycle symbol and recycle code number. There are three major types of plastics most easily collected and recycled at this time: polystyrene (PS), polyethylene terephthalate (PET), and high-density polyethylene (HDPE). These three make up approximately 50 percent of the available recyclable plastics (2).

No testing methods or testing protocols existed at the beginning of this research effort. Also, it was recognized that if recycled plastics were to be used within a reasonable time, accelerated testing of some sort would be required. This can be accomplished by using the accepted principles of time/temperature superposition (e.g., correlate excessive heating for brief periods with longer-term ambient temperature exposure). Such correlations may require several years. Test data would have to be used to predict behavior over time (without available long-term performance data). Since legislation mandated the investigation of recycled plastic fence and guardrail posts, characteristics and properties deemed essential to predict real-world performance for these items were as follows:

- Flexural strength,
- Tensile strength,
- Insect resistance (fire ants, termites),
- Soil microorganism resistance,
- Water absorption,
- Fire resistance,
- Exposure resistance to the hot and humid Florida environment, and
- Accelerated aging (oven test).

Plastic photo degradation due to ultraviolet exposure from sunlight was not expected to cause concern. Two years of post exposure have apparently justified this early decision. The initial specification for fence posts has been written addressing this concern with manufacturers.

## PRELIMINARY RESEARCH

FDOT sponsored research (6) initially focused on the stress-strain property evaluation of extruded sheets produced from recycled HDPE milk bottles. The sheets were produced by waterbath cooling of melted HDPE passed through rollers. This testing helped establish baseline parameters and guidelines for further evaluations and property measurement reproducibility. These materials are currently used commercially in Florida by two manufacturers of A-frame highway barricade panels.

The recycling process for plastics has the potential for incorporating many contaminants in the recycled plastic products. The contaminants may act as flaws and thus adversely affect the mechanical properties of the recycled plastic product. Clearly, such variations in properties will affect the specifications that can be established for any application. The use of single feedstock material and a continuous manufacturing process suggested that this recycled product had properties close to virgin plastic.

Stress-strain tensile testing indicated that property variations at deformation strains up to the yield point (a strain of approximately 0.2) within one batch of samples is less than 10 percent, and the mean property variations between batches are small (4 percent). However, the presence of dirt and other contaminants affects the failure behavior in a significant fashion. For low strain-rate testing (0.2 to 2 in./min), failure occurred at a strain of approximately 1 for the specimens containing flaws, whereas the specimens that are nearly flaw-free did not fail at a strain of 2.6 (Figure 1). These early efforts suggest that ultimate control for extruded recycled plastics must be built into the quality control scheme.

Nearly all recycled plastic post suppliers are using an unvented batch extrusion process resulting in posts with large voids (Figure 2). These voids (plus particles of metal and unmelted polymer) act as flaws and reduce the mechanical strength. Preliminary stress-strain testing indicates that these

TABLE 1 TYPICAL PLASTICS AND APPLICATIONS

Materials	Recycle		Products
	Symbol	Code #	
Polyethylene Terephthalate	PET	1	Computer and Video Tapes, Soda Bottles (2 Liter)
High Density Polyethylene	HDPE	2	Milk Bottles, Bleach Bottles
Vinyl	V	3	Water Pipe, Hose, Floor Tile
Low Density Polyethylene	LDPE	4	Supermarket Bags, Films
Polypropylene	PP	5	Soda Bottle Caps, Cassette Boxes, Battery Cases
Polystyrene	PS	6	Fast Food Containers, Utensils
ABS, PMMA, Nylon, etc.	Other	7	Toys, Contact Lenses, Rope

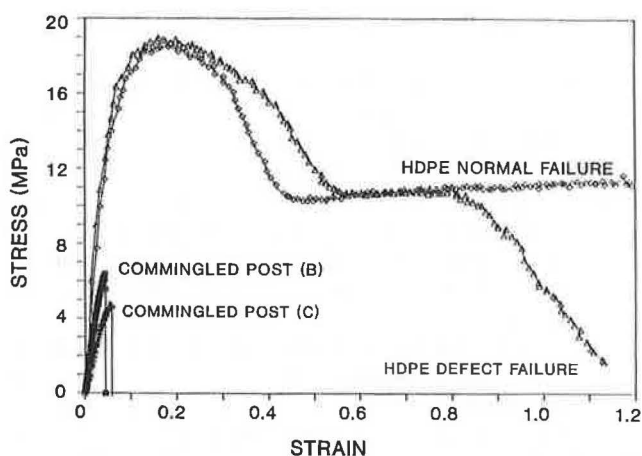


FIGURE 1 Stress-strain curve for industrial HDPE and commingled plastics.

commingled materials are more brittle than the early HDPE tests (100 percent milk bottles), as expected (Figure 1). Properties of samples taken from different portions of the posts were evaluated to determine variations due to nonuniform processing conditions. Many posts have been installed for the past 2 years at FDOT for outdoor weathering evaluation (Figure 3). It is obvious from Figure 3 that the cross-sectional size and uniformity of composition (after extruding) has an effect on long-term warpage resistance (i.e., the smaller the cross section, the greater the likelihood of warpage with age and exposure). At this time, however, post height does not appear to affect warpage within the range of post lengths being considered for use by FDOT.

### RESEARCH IN PROGRESS

Flexural testing using full-size recycled posts indicates that failure loading for certain recycled plastic posts would be greater than for concrete posts of the same size (Table 2).

This suggests that large-diameter posts may be suitable for use as guardrail posts. Ultimately, after additional laboratory tests, FHWA-mandated impact tests and crash tests will be conducted. Posts passing the crash test will be permitted for use in Florida. On the basis of preliminary whole post flexure tests, it appears that a certain amount of post void content may be desirable to help distribute the momentum of the vehicle impact.

To simulate exposure to soil microorganisms,  $\frac{1}{8}$ -in.-thick discs cut from the posts were weighed and measured, then placed at ambient temperature in five terraria each containing 25 lb of one of five unanalyzed soil types common to Florida. After being buried for several months under normal room humidity, the discs were reweighed and measured. Results indicate no mass loss or dimensional change, suggesting that soil microorganisms apparently have no effect on the posts.

Since some fence posts will probably be exposed to various water systems (brackish and fresh), it was necessary to ascertain the absorptive properties of the posts under accelerated conditions. Thus,  $\frac{1}{8}$ -in. post discs (including a wood comparison) dried, weighed, and measured, were immersed

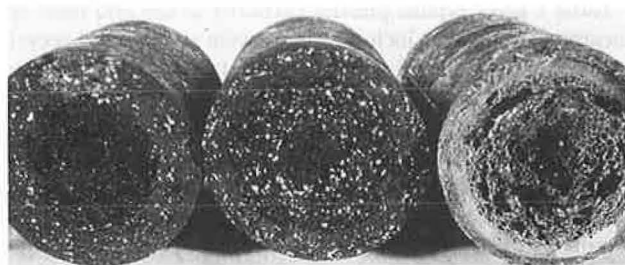


FIGURE 2 Voids and skinning effects in 6-in.-diameter posts influence the strength of the posts.

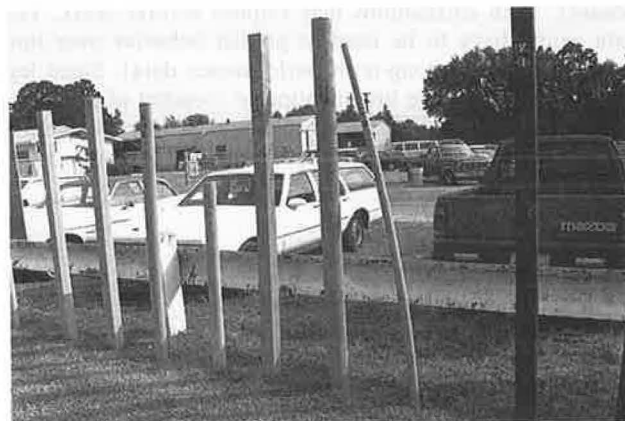


FIGURE 3 Two-year exposure test at project inception.

in boiling deionized water for up to 600 min and in boiling 5 percent saline in deionized water under pressure (to maintain constant concentration) for 500 min. The percentage changes in disc diameter (dimensional) and weight uptake are given in Table 3. It is obvious that in boiling water, dimensional changes are within acceptable limits, although Post D exceeded absorptive values for the wood disc. This is surprising but not unexpected, considering that Post D contains 50 percent sawdust. It was hoped that the plastic would act as an encapsulating agent for the sawdust and inhibit water uptake. This obviously was not the case as indicated by the high water uptake compared with the uptake of the other posts. Post D, however, is still one-ninth that of the wood control (E). In the boiling saline tests (to simulate brackish water), dimensional changes were relatively small, although Post D again gave values greater than the wood control. In terms of liquid uptake, weight changes were generally greater in boiling saline than in boiling water except for Post A. Post D again absorbed more than twice as much liquid as the other posts but was well below that of the wood. This increased water uptake may also affect insect infestation, which seems to be actuated by the addition of water.

Since the plastic posts will be exposed for very long periods to environmental conditions common to Florida, it was necessary to measure the resistance to insect attack. By design, none of the posts contains any insecticides or treating chemicals (e.g., CCA) used for wood protection. Tests were run

TABLE 2 ULTIMATE FLEXURAL STRESS OF RECYCLED PLASTIC SAMPLES FROM DIFFERENT PRODUCERS

SAMPLE CODE NAME	SHAPE	DIMENSIONS (IN)				EFFECTIVE MOMENT OF INERTIA (I) (IN <sup>4</sup> )	SECTION MODULUS (S) (IN <sup>3</sup> )	MOMENT (LB.IN.)	ULTIMATE FLEXURAL STRESS PSI
		OVERALL		CORE					
		T <sub>o</sub>	W <sub>o</sub>	T <sub>c</sub>	W <sub>c</sub>				
B2-E	R	3.5	7.5	---	---	26.8	15.3	44,637	2,915
B2-C	R	3.5	7.5	1.5	5.5	25.3	14.4	65,593	4,546
C1-C	C	6	6	4.5	4.5	43.5	14.5	58,981	4,069
C14-E	C	6	6	3.5	3.5	56.3	18.8	75,641	4,034
E7-C	R	5.5	7.5	3.5	5.0	86.1	31.3	97,717	3,120
E7-E	R	5.5	7.5	4.0	5.5	74.7	27.1	107,578	3,962
E9-C	C	6	6	4	4	51.1	17.0	78,965	4,640
E9-E	C	6	6	4.5	4.5	43.5	14.5	57,188	3,945
BC	S	3.6	3.6	2	2	12.7	7.0	21,403	3,042
CONCRETE	S	6	6	---	---	108	36	29,200	810

- Notes:
1. R = Rectangular, C = Circular, S = Square
  2. For circular samples T<sub>o</sub> = W<sub>o</sub> = Overall diameter and T<sub>c</sub> = W<sub>c</sub> = Core diameter
  3. Length of Sample = 30 in.
  4. I (effective) = I overall - I core

TABLE 3 ABSORPTION TESTS

% DIMENSIONAL DIAMETER CHANGE - 600 MINUTES IN BOILING WATER	
A.* 0.28	D. 4.8
B. 0.29	E. 4.3 (WOOD)
C. 0.53	F. 0
% WEIGHT CHANGE - 600 MINUTES IN BOILING WATER	
A. 4.7	D. 14.8
B. 6.4	E. 122.8 (WOOD)
C. 6.3	F. 2.6
% WEIGHT CHANGE - 500 MINUTES IN BOILING 5% SALINE	
A. 3.7	D. 25.9
B. 9.1	E. 149.4 (WOOD)
C. 7.0	F. 4.1
% DIMENSIONAL DIAMETER CHANGE-500 MINUTES IN BOILING 5% SALINE	
A. 0.3	D. 5.8
B. 0.1	E. 4.1 (WOOD)
C. 0.2	F. 0.4

\*Coded reference for post manufacturers.

for termite and fire ant resistance, since two post producers incorporate cellulosic material. One manufacturer uses sawdust, and the other uses manufacturing-rejected diapers. The latter includes some cellulosic absorptive material obtained during plastic liner recovery. The fire ant tests were run at the United States Department of Agriculture (USDA) Insect Labs in Gainesville, and the Formosan and Eastern termite tests were performed at the University of Florida Research and Education Center in Ft. Lauderdale (6). Both test sets exposed dried, weighed 1/8- to 1/4-in.-thick discs cut from the

posts to each test organism for 2 weeks. The tests were run in triplicate in open containers designed to keep the insects within the container. At the end of the test cycle, the discs were again dried and weighed. Any weight loss was expressed as a percentage. The results in Table 4 suggest that Posts C and D may prove unsatisfactory in a termite environment. Posts A and B also showed weight loss that may be cause for concern.

To date, fire ants have not shown any use for the materials as a food source and do not pose a threat in this respect, but Dr. Wojcik (USDA) has pointed out that fire ants may choose



TABLE 4 TERMITE DAMAGE

SAMPLE	R AVERAGE WEIGHT LOSS (G)	F AVERAGE WEIGHT LOSS (G)	PROJECTED PERCENT WEIGHT LOSS/YR
A	0.054	0.074	15.3
B	0.065	---	8.3
C	0.182	0.335	47.5
D	0.419	0.469	65.2

R - Eastern subterranean termite (*R. flavipes*).

F - Formosan subterranean termite (*C. formosanus*).

Unspecified - not distinguished between F or R.

Projected weight loss is for F.

to inhabit them. It may be necessary to add an infestation inhibitor during post manufacture. Insect testing is continuing and will be repeated, in part because of improved manufacturing processing over that used for the 2-year-old posts tested. In all the tests described, several years will be required to correlate real-world exposure tests with laboratory exposure tests.

#### STAPLE PULLOUT

As a consequence of the physical property measurements of the posts, it was decided to measure the resistance to removal of fence staples in plastic posts compared with wood posts. In general, it was discovered that the staples hold up to five times more strongly in plastic posts. Moreover, the resistance to removal increases with increasing temperature. This observation and the expected durability of the plastic posts indicate that maintenance and replacement costs could possibly be zero. Hence, cost over the lifetime of the fence post would be reduced.

#### SPECIFICATION FRAMEWORK FOR FENCE POST

On the basis of the testing described, a tentative fence specification has been proposed for recycled plastic line posts. The proposed specification will be modified on the basis of field performance of the plastic posts.

Because of the potential for using recycled plastic posts and the current lack of approved (ASTM or AASHTO) test protocols, the post manufacturers will be asked to certify that their products

- Shall be at least as durable as wood posts (35-year minimum lifetime);
- Are composed mostly of waste stream material (70 percent minimum plastic);
- Shall not exceed a specified void content;
- Shall show no chipping, cracking, flaking, peeling, or splintering;
- Shall be resistant to soil organisms and insects, especially termites and fire ants, such that no more than 10 percent loss in strength occurs over the post lifetime;
- Shall not absorb excessive water; and

- Shall contain no chemicals or additives except those designed to inhibit photo or biochemical degradation or insect infestations.

Posts from five manufacturers generally complying with these specifications have been in place for real-world exposure since April 1990 (Figure 4).

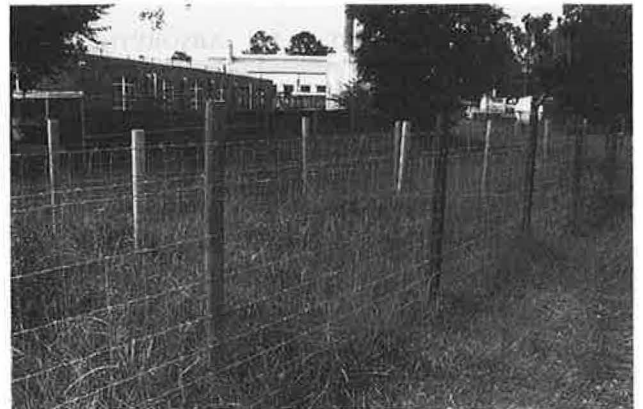


FIGURE 4 View of plastic posts from five producers with attached fencing in Gainesville, Florida.

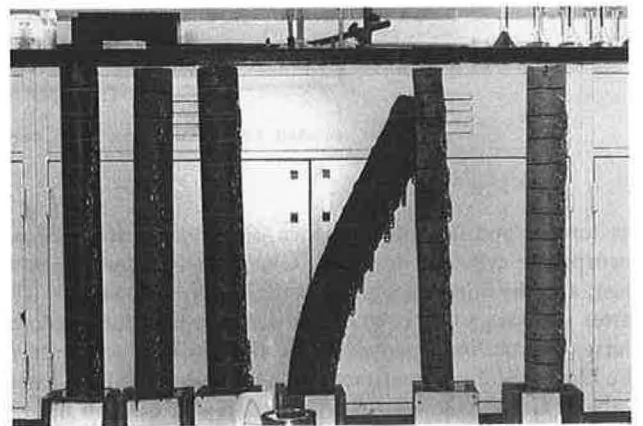
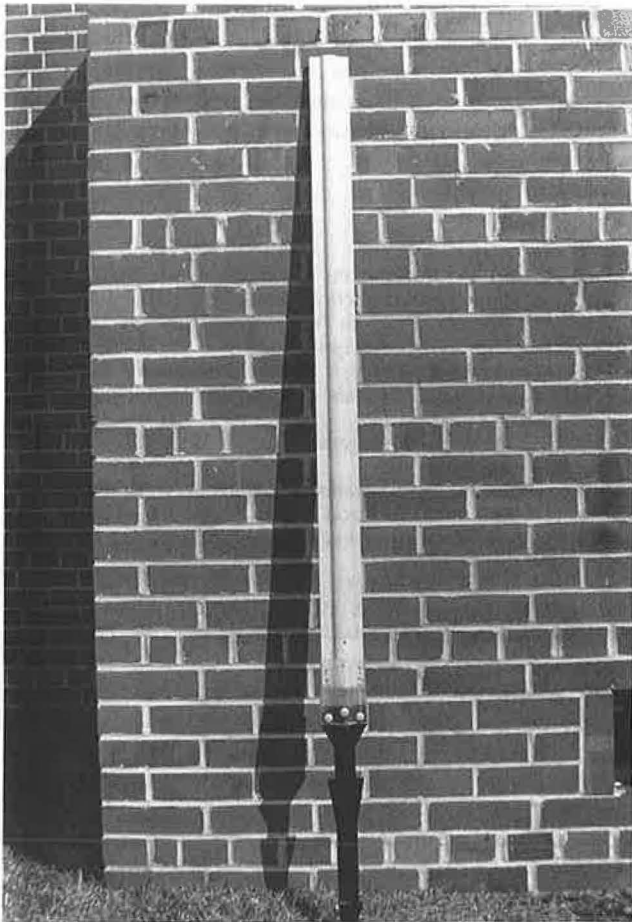


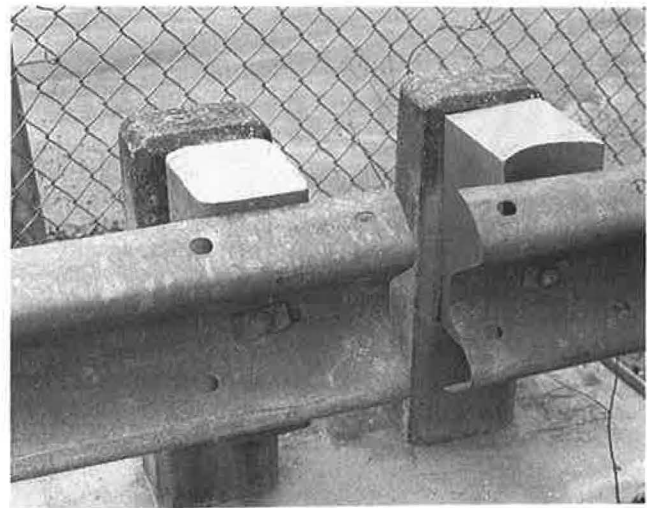
FIGURE 5 Effect of accelerated aging by oven tests. Attached chain is part of staple removal test.



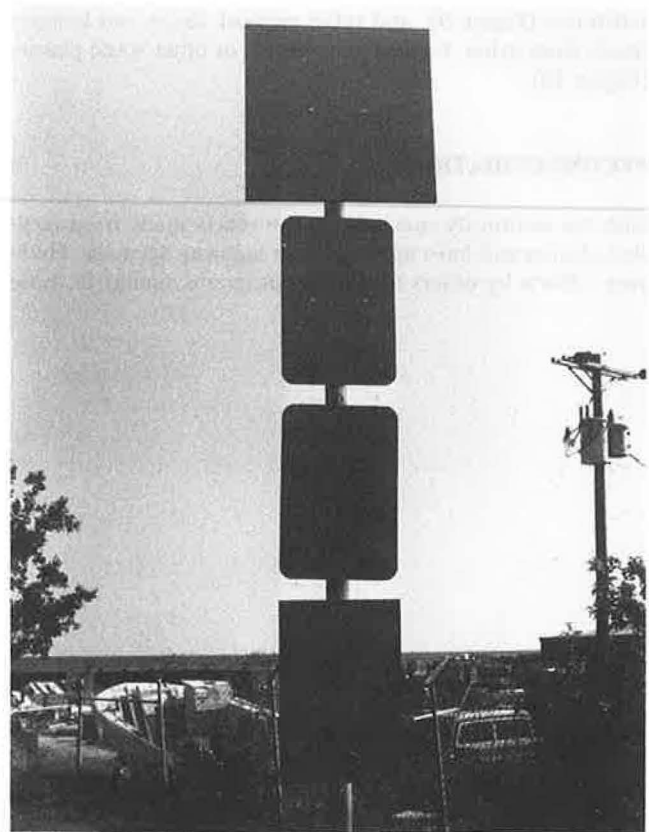
**FIGURE 6** Flexible delineator post approved for limited state use.



**FIGURE 7** Local road containing recycled plastic flexible delineator posts.



**FIGURE 8** Recycled plastic offset blocks after 6 months' exposure.



**FIGURE 9** Some recycled plastic sign substrates exposed in Marathon (Florida Keys) up to 1 year.

For the larger-diameter posts required for fence pull posts and guardrail posts, flexure tests suggest that a certain amount of void content may be beneficial, since pull posts are under tension. A field evaluation of fence pull posts will be initiated without line posts. The pull posts and braces from each manufacturer will be spaced about 10 ft apart and strung with

wire. Any residual stresses in the posts should be manifested by warpage due to fence tension and the hot Florida sun. Accelerated testing of line post sections at elevated temperatures (oven test) gives some insight into this concern (Figure 5). Since these early tests, post quality has improved to the point where high-temperature warpage (260°F, 7 hr) no longer



**FIGURE 10** Rebar support chairs approved for Florida use. *Left*, polystyrene foam—1,000-lb capacity; *middle*, another producer's chair made from polycarbonate/ABS; and *right*, conventional chair made from steel that rusts.

appears to be a concern. This may in part result from the new posts containing 70 percent minimum plastic. The earlier posts contained as little as 50 percent.

#### OTHER RECYCLED PLASTIC COMPONENTS

A wide variety of other recycled plastic FDOT components are also under study, including flexible delineator posts (Figures 6 and 7), guardrail offset blocks (Figure 8), sign substrates (Figure 9), and rebar support chairs and bolsters (made from nylon, foamed polystyrene, or other waste plastic) (Figure 10).

#### RECOMMENDATIONS

One can cautiously conclude that products made from recycled plastics will have application in highway agencies. However, efforts by others to develop programs similar to those

of FDOT should recognize environmental differences; for example, cold weather resistance is a problem in northern states, whereas fire ants are a concern in southern states. Eventually, collective data must be used to develop more definite specifications than are currently being used by FDOT.

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